SUBJECT: Lunar Exploration under Earthshine Illumination - Case 340

DATE: April 4, 1969

FROM: V. Hamza

ABSTRACT

It is shown that lunar exploration under earthshine conditions does not eliminate the problems encountered during the lunar day such as (a) the decrease in visibility due to increasing sun elevation toward the lunar noon, and (b) the restrictions imposed by the thermal environment around the lunar noon on the astronauts as well as on the equipment.

The intensity of earthshine illumination of the lunar surface might be sufficient to enable "useful" work to be done around full-earth conditions. However, for a given site location on the moon the earth elevation angle is fixed. High earth elevation angles are preferred for greater illumination levels but high earth elevation angles mean decreasing visibility. The lunar thermal environment during the lunar night is as severe as during the lunar noon.

It is suggested that a possible solution to the above problems might be obtained by conducting the lunar exploration phase toward the lunar dusk after landing on the lunar surface during the lunar afternoon. This approach will need a thorough investigation of the glare problem during a landing into the sun.

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MEMORANDUM FOR FILE

INTRODUCTION

After the first successful but brief manned lunar landing, the emphasis of the Lunar Exploration Program will be in the direction of increased staytime on the lunar surface as well as visiting some more challenging and scientifically interesting areas of the Moon. The increased staytime on the lunar surface might be of several days duration. If the philosophy of the Lunar Exploration Program followed the course chartered by the first landing mission, then the landing on the lunar surface would occur close to the morning terminator and the exploration phase of the mission would proceed toward the lunar noon. The landing near the terminator is dictated by the visibility conditions on the Moon. The best visibility of the lunar surface (low sun elevation angle) will be required for landings at some of the potential landing sites because of the increase in hazards surrounding these sites.

However, with increasing sun elevation toward the lunar noon, it is generally agreed, the visibility of the lunar surface will decrease because of lack of geometric shadows. Thus, the astronauts may encounter some problems in identifying and properly cataloging certain areas on the Moon under this condition. Furthermore, the thermal environment around the lunar noon might pose some severe restrictions on the astronauts as well as on the equipment. Lunar surface brightness temperatures calculated from the Surveyor spacecraft's data indicate strong dependence on a sun elevation angle and on a directional emission of the lunar surface. At lunar noon the surface brightness temperature rises over 200°F, and the directional emission of the lunar surface is predominant in the morning. These high temperatures give rise to an indirect infrared radiation from the surface which, together with the direct solar radiation, will impinge on the astronaut and the surrounding equipment. The rougher topography of the potential landing sites might be even a greater hazard from the thermal load considerations because of the directional emission of the lunar surface.

These two problems, the visual task degradation and the possible unbearable thermal load, increase during the period

toward the lunar noon, give a justification to some other approaches to the manned lunar exploration. This memorandum reports on the potential advantages, disadvantages, and problems associated with conducting lunar exploration missions during the earthshine phase. Earthshine in general is referred to as the illumination of the surface of the Moon by light reflected from the sunlit side of the earth. To an observer on the Moon, this is exactly analogous to the moonlight on the earth during the night, but is considerably brighter. This memorandum tries to establish the usefulness of this source of illumination for manned lunar exploration during periods when that hemisphere of the Moon is not in direct sunlight.

First, the lunar environment during earthshine is defined with special emphasis given to the areas of the potential landing sites. Discussion is centered around the expected surface brightness for the observer viewing his surroundings on the Moon, especially the dependence upon his location on the Moon and the direction in which he is looking at a particular time.

Next, the overall mission concept of lunar exploration is examined in view of this new lunar environment and its impacts on the flight hardware and astronaut lunar surface activities.

THE INTENSITY OF EARTHSHINE

From the geometry of the earth-moon system (Figure 1), it is seen that either body will undergo changes in phase as viewed from the other body. When the observer on earth sees the new moon, the moon sees the full earth, and so forth. Light refected from the full earth falls on the dark side of the moon and illuminates it.

It is convenient to specify the position of the moon in terms of phase angle θ, which is defined (Figure 1) as the angle at the center of the earth between the directions to the moon and to the sun. This angle is zero at new moon and increases to 180° at full moon.* The same convention may be used to specify the phase angle of the earth as seen from the moon. It is seen from Figure 1 that the maximum intensity of the earthlight occurs at zero phase angle and that it diminishes with phase angle as shown in Figure 2.

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*Actually, the phase angle is zero only during an eclipse of the sun and is 180° only during an eclipse of the moon.

The earth's ability to reflect sunlight onto the moon is a function of the albedo of the earth. The albedo of the earth has been established from earthlight studies by various workers in the field such as Dubois, Danjon, and Rösch. For the purposes of this memorandum it is sufficient to say that the average value of the earth's albedo is 0.4 and that seasonal variations can cause the albedo to range from 0.52 to 0.32.*

The intensity of the direct illumination from the earth will not be seriously affected by the observer's location on the moon. The phase of the earth and the degree of cloud cover will be the important factors governing the actual level of illumination. However, the manner in which the lunar surface appears to be illuminated will depend quite strongly on the observer's lunar location. The effect of a site location on earthshine illumination is shown in Figure 3. It is seen that if the landing occurs near the evening terminator then the preferred sites are the western sites (optimum at approximately 40°W) where the contribution of earthshine is larger than at central or eastern sites. The earthshine contribution to surface illumination decreases with increasing latitude as shown in Figure 4.

The lunar surface brightness is dependent on the light source angle as well as the observer's viewing angle and the azimuth angle. The geometric configuration between light source and observer is shown in Figure 5 and the lunar surface brightness can be computed from known reflective properties of the lunar surface given by the photometric function (Figure 6).

For purposes of comparison of earthshine with familiar terrestrial conditions, Figure 7 shows the whole visual spectrum of brightnesses from the absolute threshold of seeing to the upper limit of visual tolerance. Thus, for an observer on the moon, earthlight at full earth should provide illumination such as experienced on well-lighted streets at night or during natural twilight conditions just after sunset or before sunrise.

Lunar Surface Brightness by Earthshine

The maximum brightness level that can be expected on the lunar surface due to earthshine is 1.25 to 2.4 ft-Lambert. This will occur exactly at a new moon or at zero phase angle.

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*In addition to seasonal variations, daily variations can be expected depending on the amount of cloud cover.

For any other phase angle the earthshine intensity decreases
rapidly (Figure 2). The maximum brightness of the 7% reflec-
ting lunar surface is therefore

$$B = 2.4 \text{ ft-L} \times 0.07 = 0.168 \text{ ft-L}$$

as compared to about 1,000 ft-L at maximum sunlit lunar sur-
face luminance (SA = 90°). The peculiar retro-reflective
property of the lunar surface is dramatized in Figure 8. It
is seen that the brightness of the lunar surface falls rapidly
from its maximum value, which occurs when the viewing angle
equals sun angle. Thus if the maximum lunar surface bright-
ness due to earthshine should be sufficient for the lunar
exploration work then it must be directed so that it coincides
with the astronaut's viewing angle. This is, however, precisely
the condition of washout or zero contrast. Furthermore, the
earth elevation angle is fixed for a given site location on
the moon and thus a constraint on the range of earth elevation
angles will dictate the selection of the site. For greater
illumination levels, high earth elevation angles are preferred,
but high earth elevation angles mean loss of geometric shadows
and consequently, decreasing visibility.

PERFORMANCE OF THE HUMAN EYE

        The performance of the eye under low illumination has
been extensively studied under laboratory conditions. It should
be understood that discrepancies between laboratory and field
conditions exist, however, the conclusions reached under labora-
tory conditions often suggest ideas that can be tested in more
realistic trials. A considerable amount of work by Blackwell
has been done on techniques of scanning during the day. In
recent years the Armed Forces directed their emphasis to work
on visual search at night or during reduced illumination.

The Visual Threshold Contrast of the Human Eye

        The threshold contrast is a function of the adaptation
brightness and the angle δ which the object subtends at the eye.
The adaptation brightness can be the sky brightness or, in labor-
atory experiments, the brightness of the background screen. The
angle δ is a function of the object area A and the distance R
between the object and the observer. For circular targets*

$$\delta = 3.88 \frac{\sqrt{A}}{R}$$

where δ is measured in minutes of arc, A in square meters, and
R in km.

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        *This relationship can also be used for square and nearly
square objects.

It was found, J. J. Vos, et al.,[11] that there is no
sudden borderline between the regions of absolute visibility
and invisibility, but there exists a transition zone wherein
an observer or a group of observers can see an object only
with a certain probability, which is called the probability
of seeing, p_s. The smaller the threshold contrast of the eye,
the larger is the sighting range for a given target size. It
is important to recognize that there exists a certain angle
δ_k, called the critical angle, which depends on the adaptation
brightness B_A, such that different relationships between the
threshold contrast and the visual angle δ are valid depending
whether δ is greater or smaller than the critical angle δ_k.
The approximate relationship between the critical angle δ_k
and the adaptation brightness B_A is shown in Figure 9.

Targets which subtend an angle $\delta(B_A)$ larger than or
equal to $\delta_k(B_A)$ are called area targets and those for which
$\delta(B_A)$ is smaller than $\delta_k(B_A)$ are called point sources. For
point sources, the product of contrast and area of the stimulus
required for 50% detection is constant. This relationship is
not valid for area targets. Performance of the human eye for
large area pattern recognition with varying contrast is shown
in Figure 10. The maximum sighting range becomes zero when
the contrast of a target is equal to a threshold contrast value
of the human eye. The adaptation brightness at which this will
happen for a certain target with a given contrast may be called
the specific adaptation brightness. Figure 11 shows the specific
adaptation brightness as a function of the visual angle subtended
by the target at the eye for contrast values of 1.0 and 0.4
(using the data of Vos et al. for a very small probability of
seeing). It is seen that this brightness decreases with larger
δ and the curves approach horizontal asymptotes for larger values
of δ. Below the specific adaptation brightness corresponding to
these asymptotes, no object can be seen any more. For compar-
ison with other publications, the conversion table for the com-
monly used units of brightness may be useful (Table 1).

In daylight vision, the object of scanning is to bring
the image of each part of the field onto the most sensitive part
of the retina which is the central fovea. Away from this very
small area, acuity, and correspondingly the range at which a
target can be detected, fall off very rapidly.

In night vision, on the other hand, the fovea is the least sensitive part of the retina. The most sensitive part is an annular area around the fovea. This area depends on the illumination, in general, the darker the surrounding the most sensitive part of the retina moves further from the fovea, and the most sensitive area gets larger. Because of this enlarged sensitive retinal area, close scanning during the night is unnecessary and the visual field can be covered in a number of fairly large steps. If possible, the fixation points should be associated with definite objects in the field of view.

Fairly rapid movement of the eyes is natural in scanning an area in daylight, however, when low illumination is the limiting factor in vision, then in order for the eye's capacity for temporal summation to have full effect it is desirable to fixate for longer periods. The threshold intensity is inversely proportional to the time for fixation times up to about 0.1 second and it is inversely proportional to the square root of that time for longer periods, up to 1 second. Longer fixation leads to fading and shorter fixation results in the loss of some available information.

It is a well known fact that exposure to light reduces the eye's sensitivity to faint illumination and it takes time to recover, e.g., after leaving a lighted room at night, maximum sensitivity may not be reached until after twenty minutes in darkness.

In a brief summary, the human eye is a very adaptable device. From the intensity of earthshine illumination of the lunar surface it can be concluded that it is sufficient to enable useful work. The word "useful" needs some more explanation. It certainly will be sufficient for astronauts walking on the surface as well as performing some simple tasks such as instrument deployment. Perhaps it might be necessary to use an artificial light source for some special occasions (very low albedos in certain areas). However, whether this lighting will be good for landing a spacecraft (LM or LFU) on the lunar surface is very doubtful.* For greater illumination levels, larger earth elevation angles will be preferred, but high elevation angles (similarly high sun elevation angles during the day) mean decreasing visibility on the lunar surface because of the surface peculiar reflection properties. Simulation studies as

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*From Apollo 8 observations, it was possible to determine features, craters, and terrain in the light available from the earth provided the crew was dark adpated. However, Col. Anders stated, "I would definitely say that the night landing or landing on the moon in an earthshine condition would be unacceptable from a visibility standpoint."

well as more actual visual experience from the orbiting CSM
will be required to determine minimum luminance levels for
safe landing at a predetermined site.

LUNAR THERMAL ENVIRONMENT

The temperature on the lunar surface depends upon
the following factors:

a.   Incident solar radiation (2.0 cal cm^{-2} min^{-1} at
the subsolar point; zero beyond the terminator).

b.   Local surface reflectance (from data in the visible
region of the spectrum, the reflectance of the lunar
surface varies from 0.05 to 0.17). The brighter areas
(greater reflectance) absorb less of the incident
solar radiation than the darker areas (smaller reflec-
tance). Consequently, there will be local temperature
variations on the Moon due to differences in surface
reflectance. The brighter areas will be cooler than
the darker areas.

c.   Local surface geometry - a perfectly smooth spherical
surface would not receive radiative heat transfer
between any parts of its surface since no part of
the surface can "see" any other part. However, the
lunar surface is not a smooth surface on a scale of
kilometers and therefore an appreciable heat trans-
fer takes place (concave depressions, valleys, and
crevices might become focal points for reflected
and reradiated solar energy). This might have the
effect of causing the temperatures of such features
to be higher than that of the surrounding level areas
having the same reflectance and thermal properties.

d.   Local thermal properties - the incident solar radiation
that is absorbed by the lunar surface can be accounted
for in the following manner:

(1)   reradiated at the local surface temperature

(2)   stored in the material on the lunar surface

(3)   conducted into the interior of the moon.

The significant parameters for determining the local
surface temperature are ϵ, emissivity of the surface,

ρ, bulk density of the surface material, c, the specific heat, and k, the thermal conductivity. The parameters ρ, c, and k combine to form the quantity known as thermal inertia:

$$\gamma = (k\rho c)^{-1/2}$$

This quantity can be evaluated by fitting theoretical temperature curves to measurements of lunar emission during eclipses and lunations. Such curves are shown in Figure 12 which shows the lunar surface brightness temperatures after sunset for Surveyors I, V, and VI. All the spacecraft-sensed lunar surface temperatures are consistent with an effective γ of about 500. This is in contrast to a value of 1100 predicted from earth-based eclipse data. Several possible explanations for this contradiction are given in Reference 24.

(1)   The landing site consists of rocks that cool slower than the surface.

(2)   An incorrect value of heat flow from the interior of the spacecraft compartments may have been used.

(3)   Radiation from the spacecraft may be heating the lunar surface in the immediate vicinity.

(4)   The telescope (earth-based data) was unable to resolve thermal inhomogeneities to a scale comparable with the Surveyor landing sites.

The emissivity of the lunar surface is related to the surface reflectance which varies according to material composition. Until the day when a sample of the lunar surface can be analyzed, the emissivity can be only approximated. That is why all the calculations made from Surveyor data refer to the lunar surface brightness temperature – the temperature at which a blackbody would need to be operated in order to emit the same amount of radiation as the gray body being observed.* Figure 13 compares the lunar surface brightness temperatures for Surveyors I, III, V, and VI (NASA SP-166). At the subsolar point (lunar noon) the surface has the temperature of boiling water and it

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*This comparison is usually made in some narrow spectral interval.

falls to about 100°F at a sun elevation angle of about 20° and 160°. At the evening terminator the temperature falls very rapidly from the freezing point of water at a rate of about 10°F per hour and it reaches minimum during the lunar night of about -250°F.

Due to the negligible lunar atmosphere, heating by convection should not be a problem. It appears that localized "hot spots" can arise due to purely geometrical effects; namely, local slopes causing tilting of the local surface toward the sun and local topography acting to trap the incident radiation. Lunar surface temperatures derived from Surveyors, I, III, and VI (Figure 13) suggest directional emission of the lunar surface in the morning, but not in the afternoon (Ref. 24). The surface temperature extremes range from about -250°F during the lunar night to about +200°F at lunar noon.

Thermal Control of Objects on the Lunar Surface

The above discussion of the lunar thermal environment can certainly be summarized as extreme. In order to provide man on the lunar surface with a life-sustaining environment together with the best operational equipment which helps man not only to facilitate the exploration of the moon but more importantly to bring him safely back home, the Environmental Control System (ECS) has been developed to protect the equipment from overheating or freezing. This system has been designed primarily for lunar day operation. The components of the ECS generally were selected from those which have previously demonstrated high reliability rather than from those that only showed potential. Duplication of the most critical components was the logic of the design approach. It is therefore obvious that certain changes must be incorporated in the ECS in order for the equipment to function properly during the lunar day/night cycle. Some of the most obvious changes* in thermal control are shown in Tables II and III (obtained from a Grumman presentation on December 12, 1968).

The lunar day operation has one more important aspect for the thermal control of both extremes - overheating and freezing - namely, by periodic turning of equipment (wherever applicable) away or toward the sun. On the other hand, some of the design problems associated with the thermal gradient and the radiator size and weight might be eliminated during the lunar night operation.

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*These changes provide only estimates of additional power required to make certain LM equipments operational. No mention is given to some more basic considerations as, e.g., what will happen to the propellant when it freezes, what additional power is needed and what changes must be made to the astronaut's EVA suit and the tools required for exploration.

SUMMARY

The reasons for looking into the problem of lunar exploration under earthlight illumination were stated in the introduction as:

  a.   decrease in visibility with increasing sun eleva-
        tion toward the lunar noon, and

  b.   restrictions imposed by the thermal environment
        around the lunar noon on the astronauts as well
        as on the equipment.

The performance of the human eye under low illumination differs from that during the day, but the eye is a very adaptable device. From the intensity of earthshine illumination of the lunar surface it can be concluded that it is sufficient to enable useful work. The word useful needs some more explanation. It certainly will be sufficient for astronauts walking on the surface as well as performing some simple tasks. Perhaps it might be necessary to use an artificial light source for some special occasions (very low albedos in certain areas). However, whether this lighting will be good for landing a spacecraft (LM or LFU) on the lunar surface is very doubtful (this conclusion is also supported by Apollo 8 observations). For greater illumination levels, larger earth elevation angles will be preferred, but high elevation angles (similarly high sun elevation angles during the day) mean decreasing visibility on the lunar surface because of the surface peculiar reflection properties. Simulation studies as well as more actual visual experience from the orbiting CSM will be required to determine minimum luminance levels for safe landing at a predetermined site. For landing near the evening terminator the western sites are preferred.

The lunar thermal environment during the lunar night is as severe as during the lunar noon. The temperature of the lunar surface falls to more than -200°F. While the LM is designed to operate during the lunar day, some changes in design for an operation during the lunar night would be required.

It seems that lunar exploration during earthlight is not the solution to the existing problem. The visibility of the lunar surface and likewise the thermal environment will not improve. One other possible approach to lunar exploration, which might solve the above mentioned problems, is to land on the lunar surface during the lunar afternoon and conduct the exploration phase toward the lunar dusk. The improvement in

visibility during the lunar afternoon is shown in Figures
14(a) and (b) for two different viewing angles. It is seen
that the improvement in visibility during the lunar afternoon
is essentially independent of viewing angle. Likewise the
surface brightness temperature becomes more tolerable as
shown in Figure 13. Several studies are now underway to deter-
mine the feasibility of this approach. Recently, R. Troester
considered the reduction in lunar surface visibility due to
glare during a landing into the sun. He postulated an ana-
lytical glare model and concluded that a descent directly
into the sun provides good visibility. This is quite an
encouraging result because a major obstacle to the considera-
tion of a lunar landing against the sun has been the uncer-
tainty in the effect of glare on the visibility of lunar
surface features. A further advantage of this approach would
result in more operational flexibility by increasing the
available launch window due to modification of the lighting
constraint.

2015-VH-acm   V. Hamza

Attachments
  Bibliography
  Tables 1 - 3
  Figures 1 - 14
  Appendix

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TABLE I

UNITS	C/M²	FT.L. OR FT.C.	L.
CANDLES PER SQUARE METER (C/M²)	1	0.292	0.314×10^{-3}
FOOT LAMBERTS (FT.L) EQUIVALENT FOOT CANDLES (FT.C.)	3.43	1	1.08×10^{-3}
LAMBERTS (L)	3183	929	1

CONVERSION FACTORS FOR SOME BRIGHTNESS UNITS

TABLE II

EFFECTS OF SOLAR POSITION ON ELM THERMAL CONTROL

	LUNAR NOON	TERMINATOR			LUNAR MIDNIGHT
		DAY	DAY/NIGHT	NIGHT	
DUTY CYCLE OF HEATERS (%) RCS* (768 WATTS) RENDEZVOUS RADAR (80 WATTS) S-BAND ANTENNA (52 WATTS)	0	35	35	35	45
VEHICLE STRUCTURAL LOAD (BTU/HR)	1000	300	0	-300	-1000
RADIATOR ENVIRONMENTAL HEAT FLUX (BTU/HR/SQ. FT) 100 80 60 40 20 0 ▯ VERTICAL SIDE OF DESCENT STAGE ▨ HORIZONTAL EXTENDED ▩ GEOMETRICALLY SELECTIVE RADIATOR	-195	-185			
ECS RADIATOR SIZE (SQ.FT)	65	60	54	48	35
FUEL CELL RADIATOR SIZE (SQ.FT) (SIDE OF D/S IN LUNAR ORBIT; EXTENDED ON LUNAR SURFACE)	16	15	15	14	13

*RCS ALLOWED TO FREEZE AND THAWED 1 HOUR PRIOR TO LAUNCH WITH 1000W (MAX) OF HEATERS

GRUMMAN PRESENTATION "3-DAY EXTENDED LM EARTHSHINE MISSION-STUDY REVIEW" ON DEC. 12, 1968.

TABLE III

EPS WEIGHT - RELIABILITY SUMMARY

CONFIGURATION	DELTA WEIGHT - LB WITH RESPECT TO REFERENCE APOLLO LM		RELIABILITY MISSION SUCCESS FOR 3-DAY MISSION
	LUNAR NOON	TERMINATOR DAY	
ALL DESCENT BATTERIES [1]	+298	+457	.994769
ALL ASCENT BATTERIES [2]	+516	+655	.991234
1 FUEL CELL + 1 ASCENT BATTERY	-164	-162[3]	.988480
2 FUEL CELLS + 1 ASCENT BATTERY	+11	+13[3]	.999871[4]
SOLAR ARRAY + 3 DESCENT BATTERIES [5]	+41	+18	.999920
SOLAR ARRAY + 3 ASCENT BATTERIES [5]	+39	+11	.999914

NOTES:
(1) 6 FOR LUNAR NOON, 7 FOR ALL OTHER CONDITIONS
(2) 8 FOR LUNAR NOON, 9 FOR ALL OTHER CONDITIONS
(3) FOR TERMINATOR NIGHT, SUBTRACT 2 LB; FOR LUNAR MIDNIGHT, SUBTRACT 4 LB
(4) ONE OF THE TWO FUEL CELLS IS REDUNDANT - REDUNDANCY REQUIRED TO OBTAIN DESIRED CONFIGURATION RELIABILITY - ALL OTHER CONFIGURATIONS ARE NON-REDUNDANT
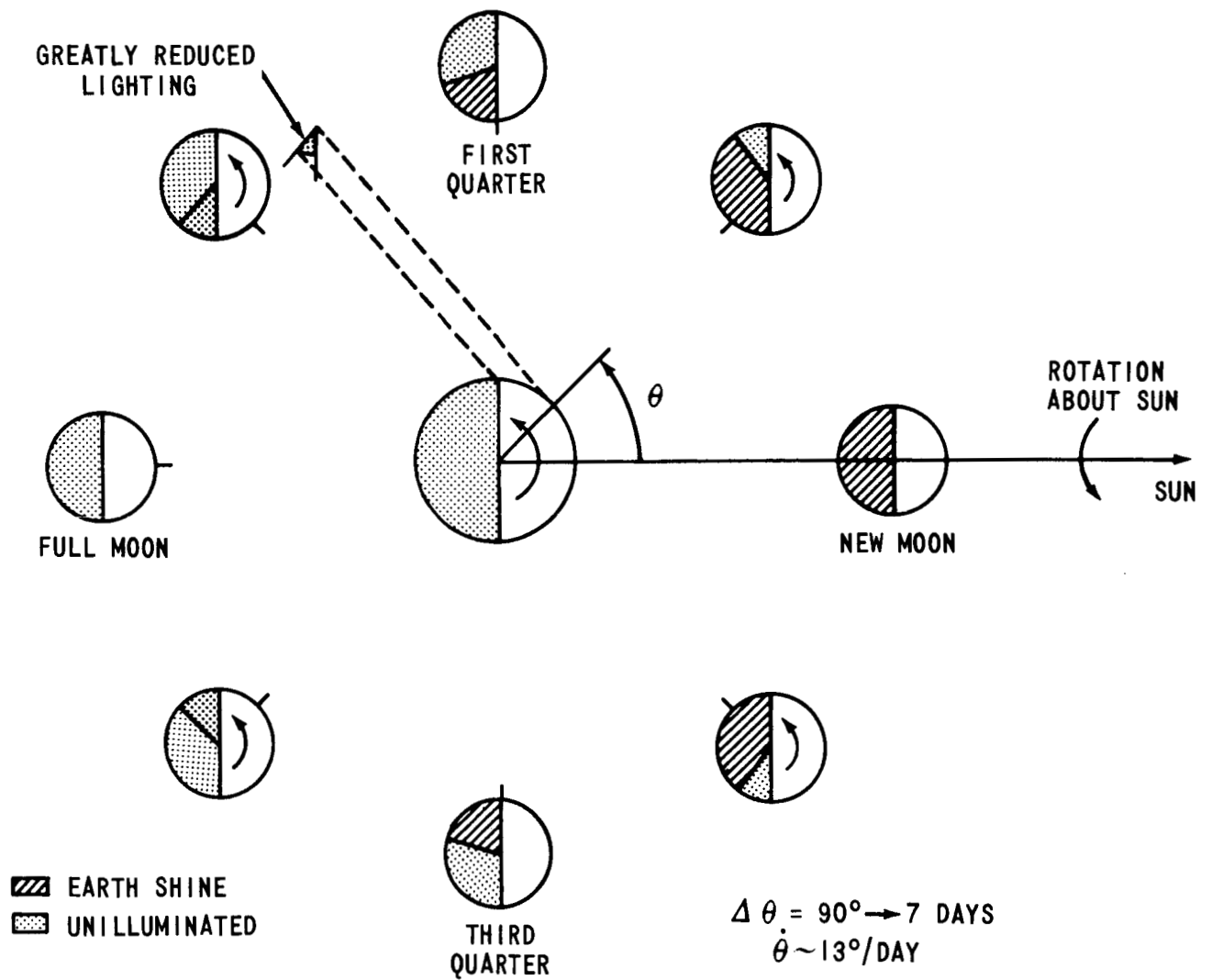(5) DAY MISSIONS ONLY

GRUMMAN PRESENTATION "3-DAY EXTENDED LM EARTHSHINE MISSION-STUDY REVIEW" ON DEC. 12, 1968

GREATLY REDUCED
LIGHTING

FIRST
QUARTER

θ

ROTATION
ABOUT SUN

SUN

FULL MOON

NEW MOON

▨ EARTH SHINE
▨ UNILLUMINATED

THIRD
QUARTER

$\Delta \theta = 90° \longrightarrow 7$ DAYS
$\dot{\theta} \sim 13°/$DAY

FIGURE I – THE GEOMETRY OF EARTH-MOON SYSTEM
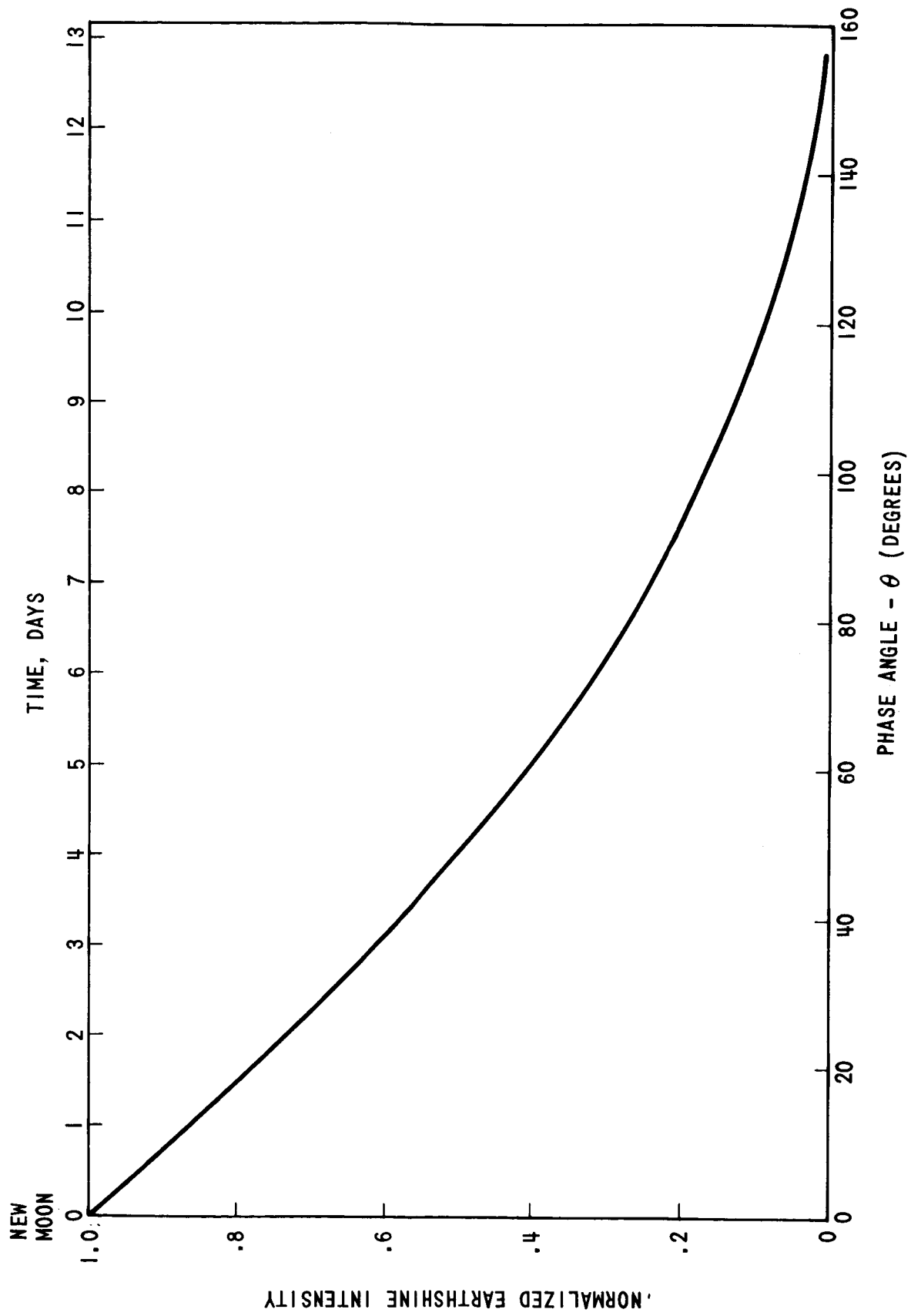
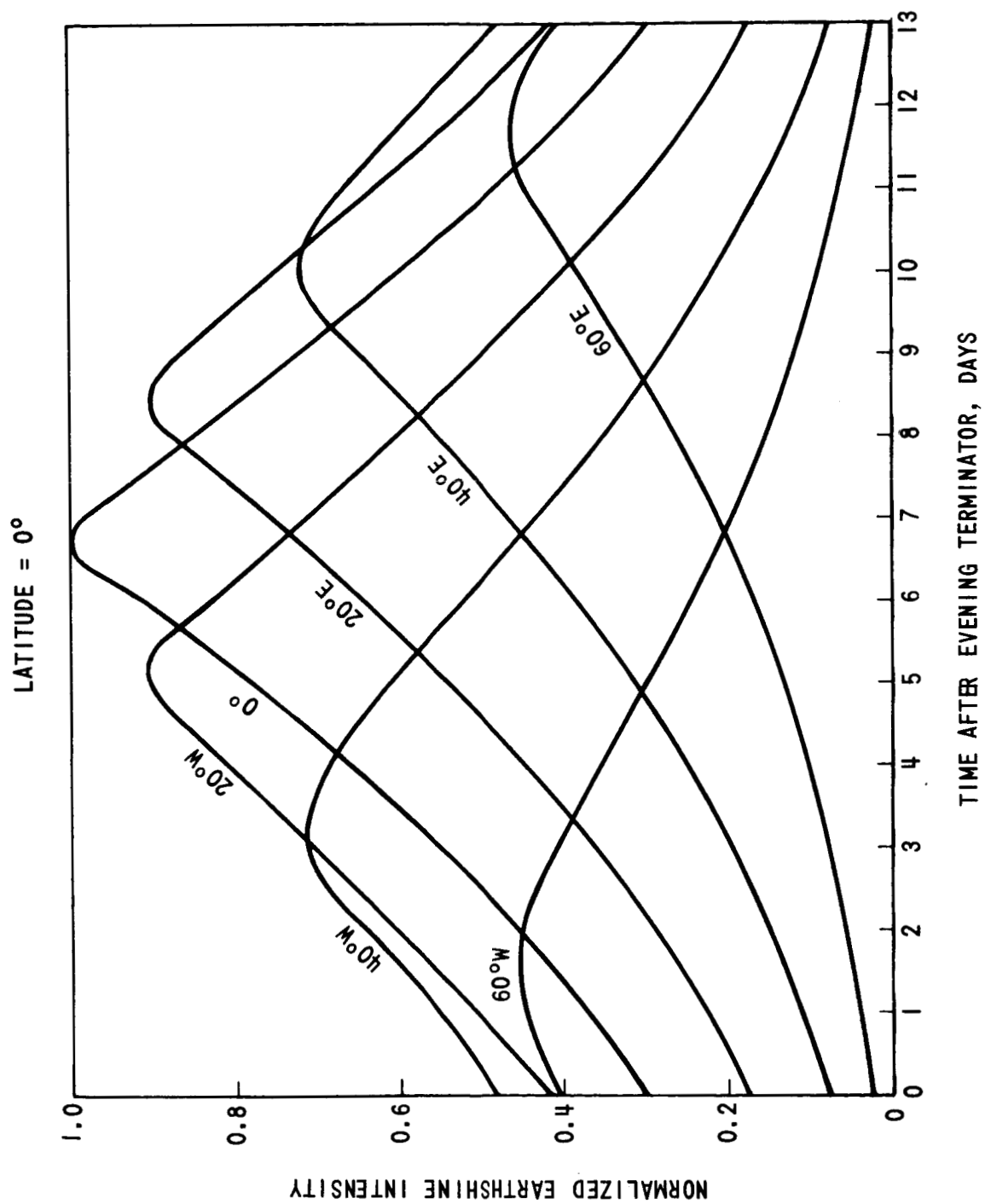FIGURE 2 - EARTHSHINE INTENSITY ON MOON AS A FUNCTION OF EARTH PHASE ANGLE

LATITUDE = 0°

NORMALIZED EARTHSHINE INTENSITY

TIME AFTER EVENING TERMINATOR, DAYS

FIGURE 3 — MEAN CONTRIBUTION OF EARTHSHINE TO THE ILLUMINATION OF SITES IN THE EQUATORIAL ZONE
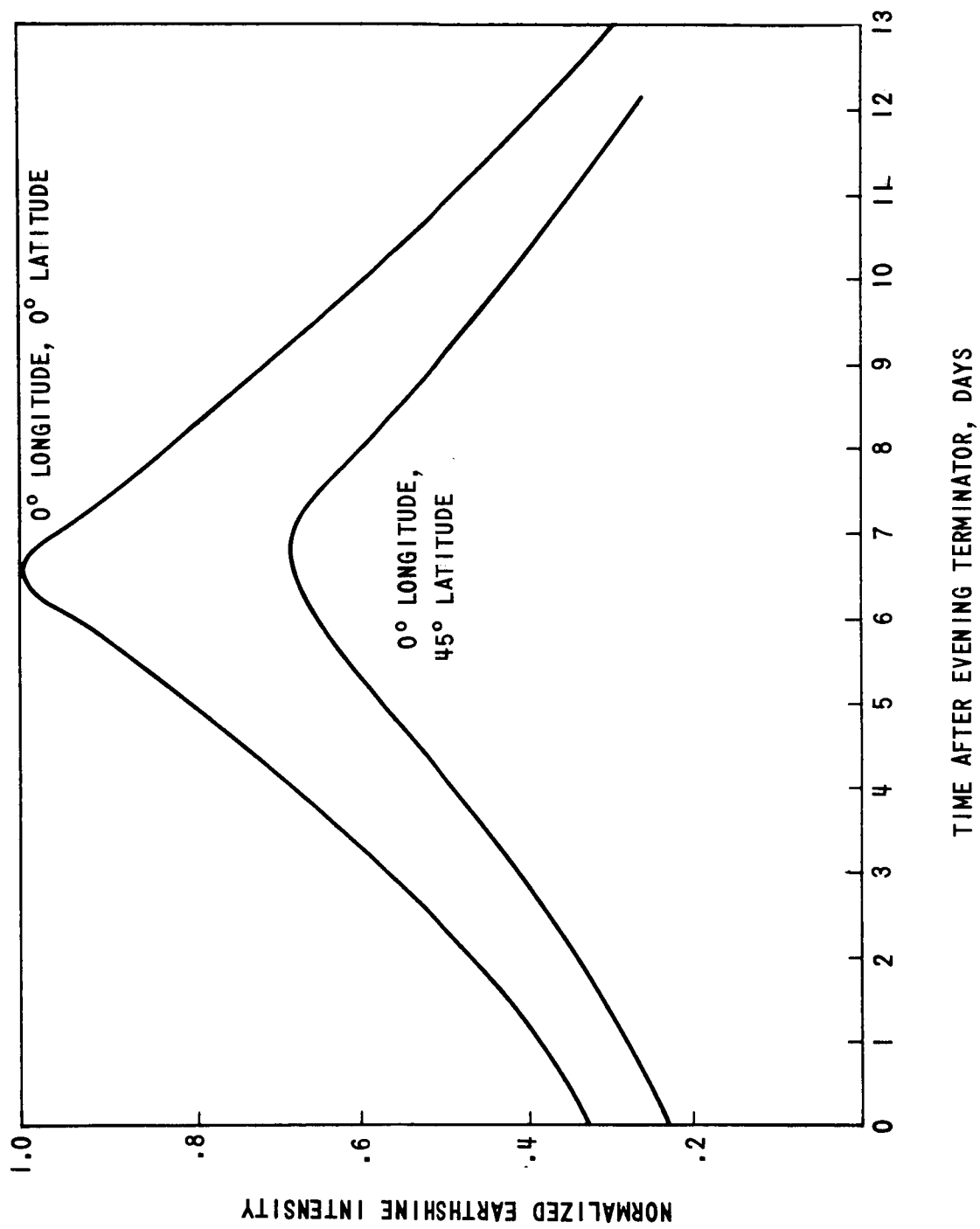
FIGURE 4 - MEAN CONTRIBUTION OF EARTHSHINE TO A SITE AT (0°, 0°) AND (0°, 45°)
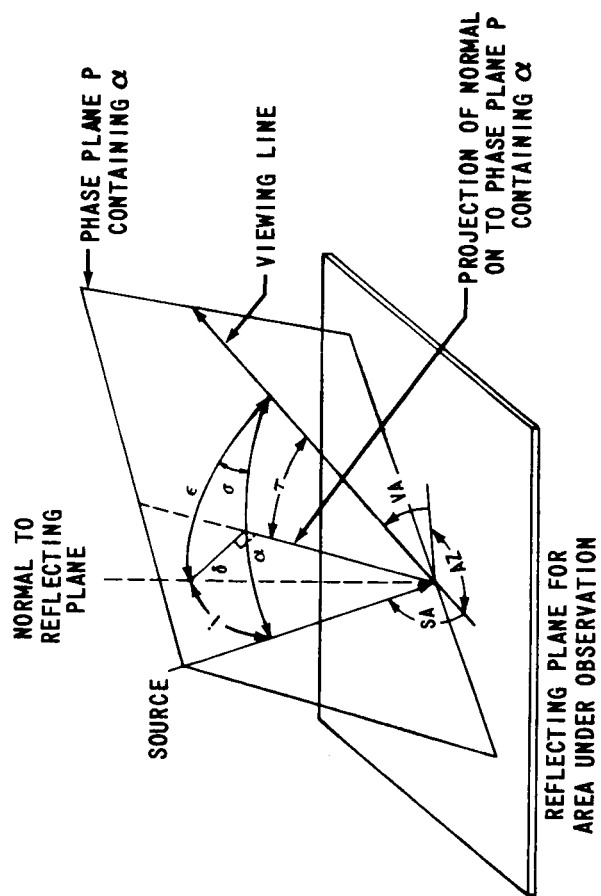
NORMAL TO
REFLECTING
PLANE

PHASE PLANE P
CONTAINING α

VIEWING LINE

PROJECTION OF NORMAL
ON TO PHASE PLANE P
CONTAINING α

ε

σ

τ

VA

δ

α

SA

AZ

i

SOURCE

REFLECTING PLANE FOR
AREA UNDER OBSERVATION

i = ANGLE OF INCIDENCE

ε = ANGLE OF EMITTANCE

α = PHASE ANGLE

τ = PROJECTION OF ANGLE ε ONTO PHASE PLANE P

PROJECTION OF NORMAL
ON TO PHASE PLANE

VIEWING

SOURCE

α

τ

REFLECTING PLANE
UNDER OBSERVATION

−τ

PROJECTION OF
NORMAL

SOURCE

VIEWING

α

τ

−τ

PROJECTION OF
NORMAL

VIEWING

SOURCE

τ

α

+τ
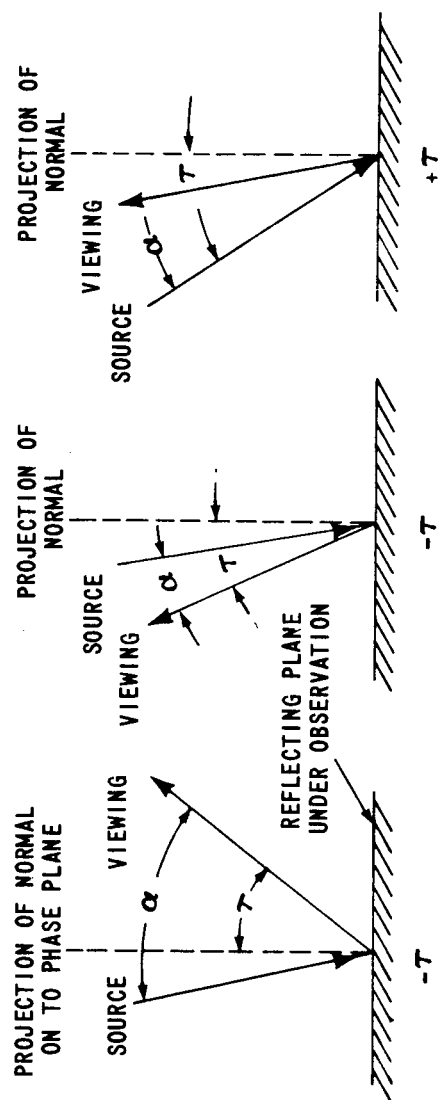
FIGURE 5 GEOMETRY OF VIEWING AND LIGHTING ON THE LUNAR SURFACE
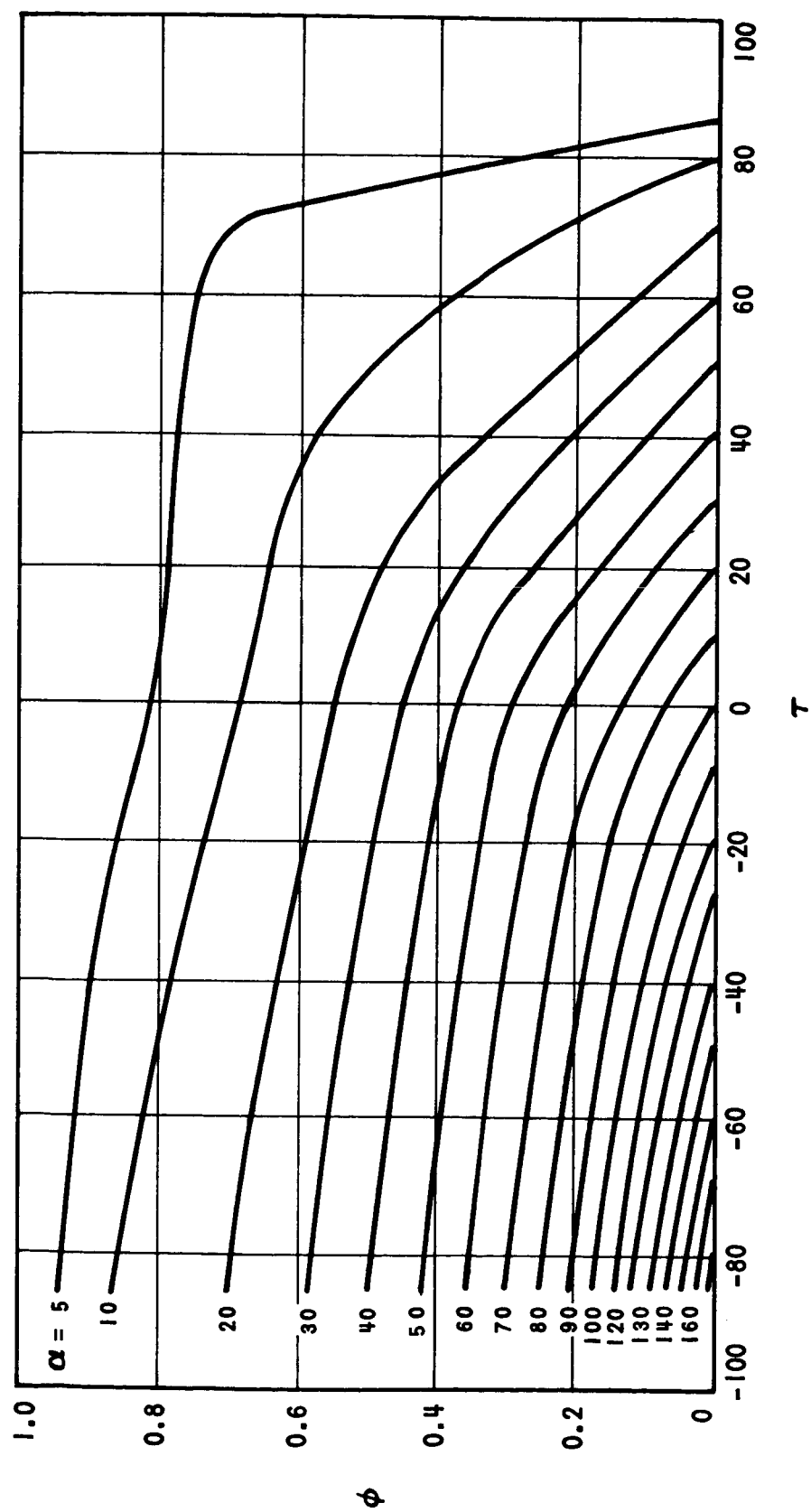
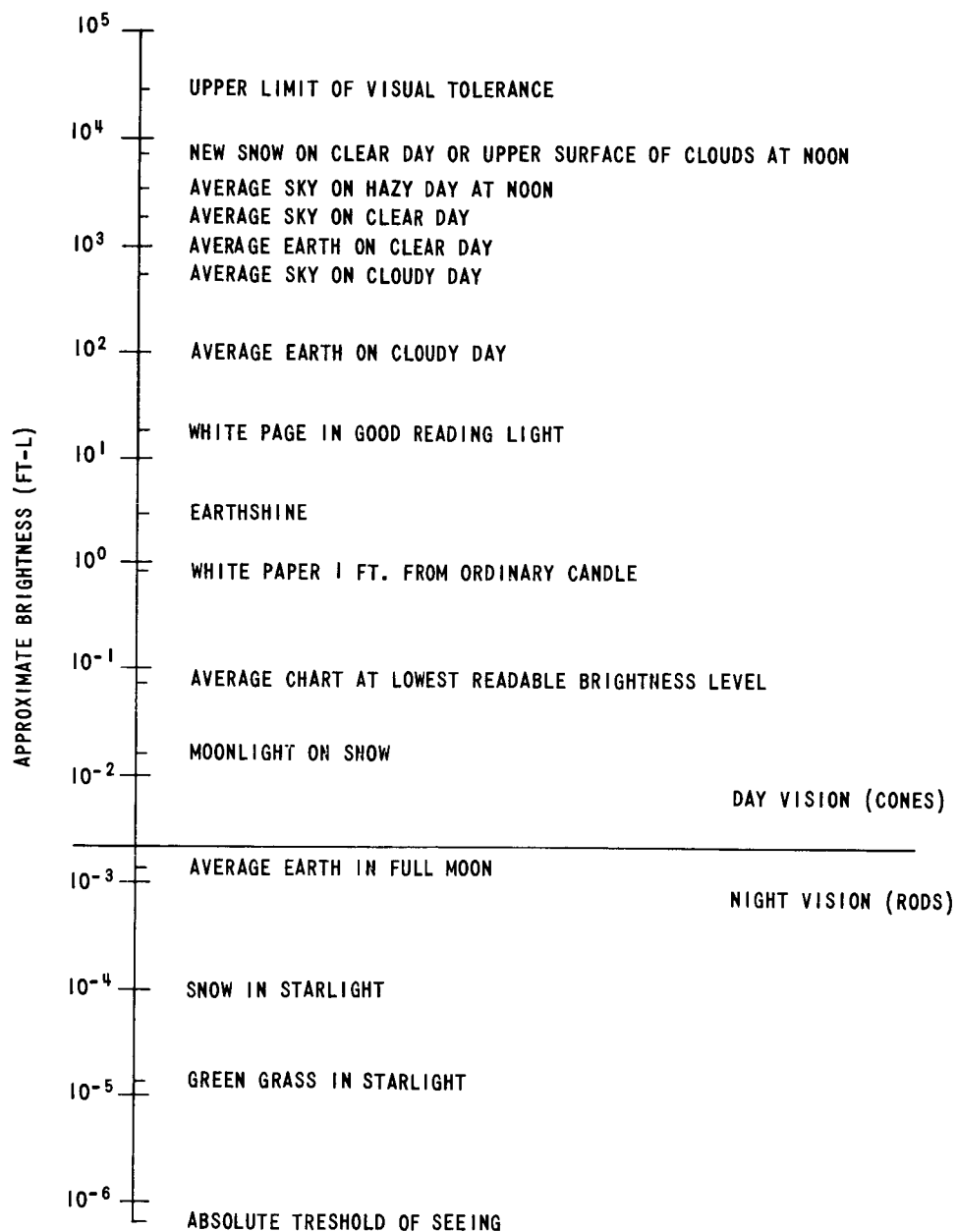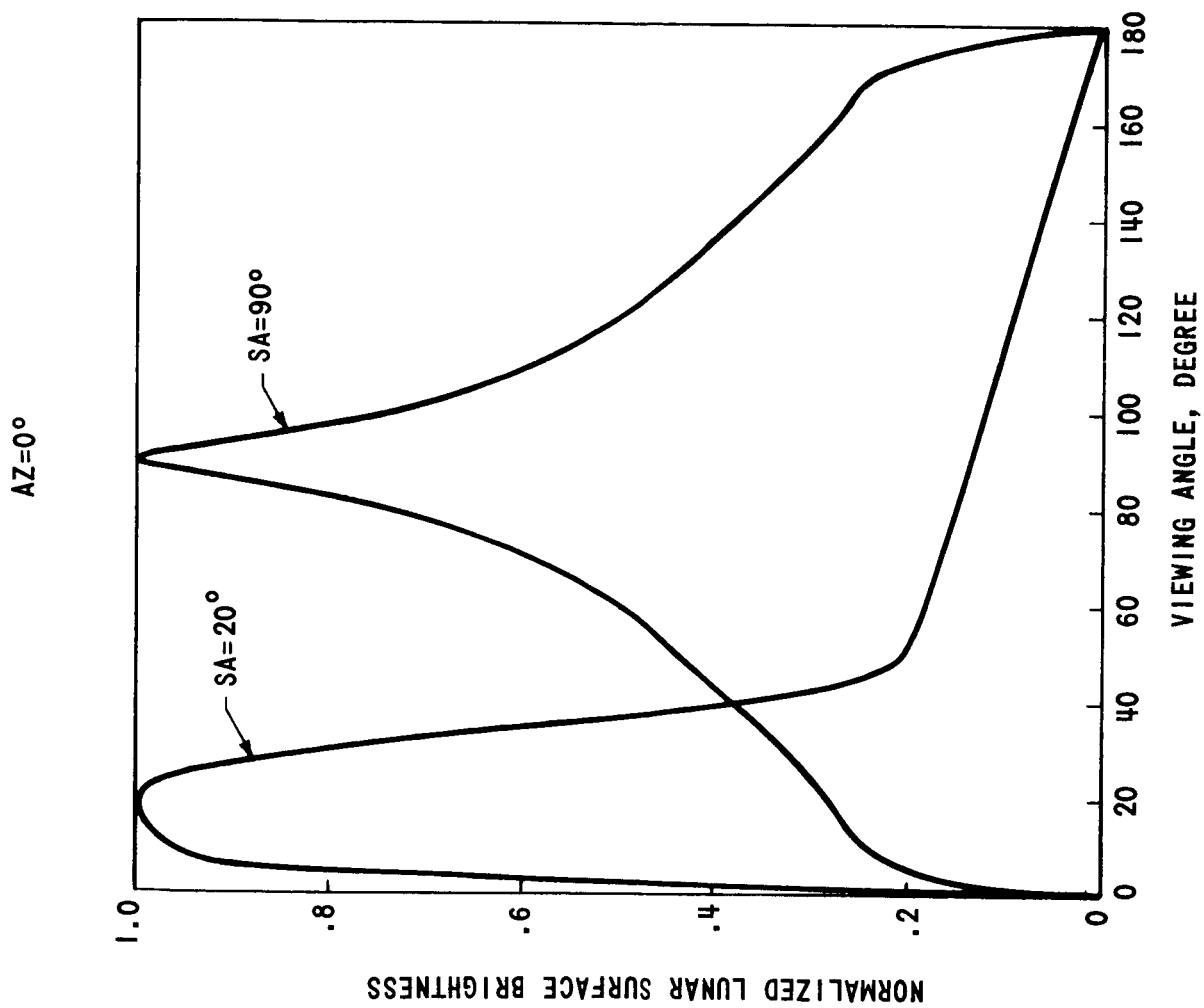FIGURE 6   LUNAR PHOTOMETRIC FUNCTION (FEDORETS)

APPROXIMATE BRIGHTNESS (FT-L)

10^5 —

UPPER LIMIT OF VISUAL TOLERANCE

10^4 —

NEW SNOW ON CLEAR DAY OR UPPER SURFACE OF CLOUDS AT NOON

AVERAGE SKY ON HAZY DAY AT NOON
AVERAGE SKY ON CLEAR DAY

10^3 —

AVERAGE EARTH ON CLEAR DAY
AVERAGE SKY ON CLOUDY DAY

10^2 —

AVERAGE EARTH ON CLOUDY DAY

10^1 —

WHITE PAGE IN GOOD READING LIGHT

EARTHSHINE

10^0 —

WHITE PAPER 1 FT. FROM ORDINARY CANDLE

10^{-1} —

AVERAGE CHART AT LOWEST READABLE BRIGHTNESS LEVEL

MOONLIGHT ON SNOW

10^{-2} —

DAY VISION (CONES)

10^{-3} —

AVERAGE EARTH IN FULL MOON

NIGHT VISION (RODS)

10^{-4} —

SNOW IN STARLIGHT

10^{-5} —

GREEN GRASS IN STARLIGHT

10^{-6} —

ABSOLUTE TRESHOLD OF SEEING

FIGURE 7 - VISUAL SPECTRUM OF BRIGHTNESSES

AZ=0°

SA=90°

SA=20°

VIEWING ANGLE, DEGREE

NORMALIZED LUNAR SURFACE BRIGHTNESS

FIGURE 8 – NORMALIZED LUNAR SURFACE BRIGHTNESS vs. VIEWING ANGLE
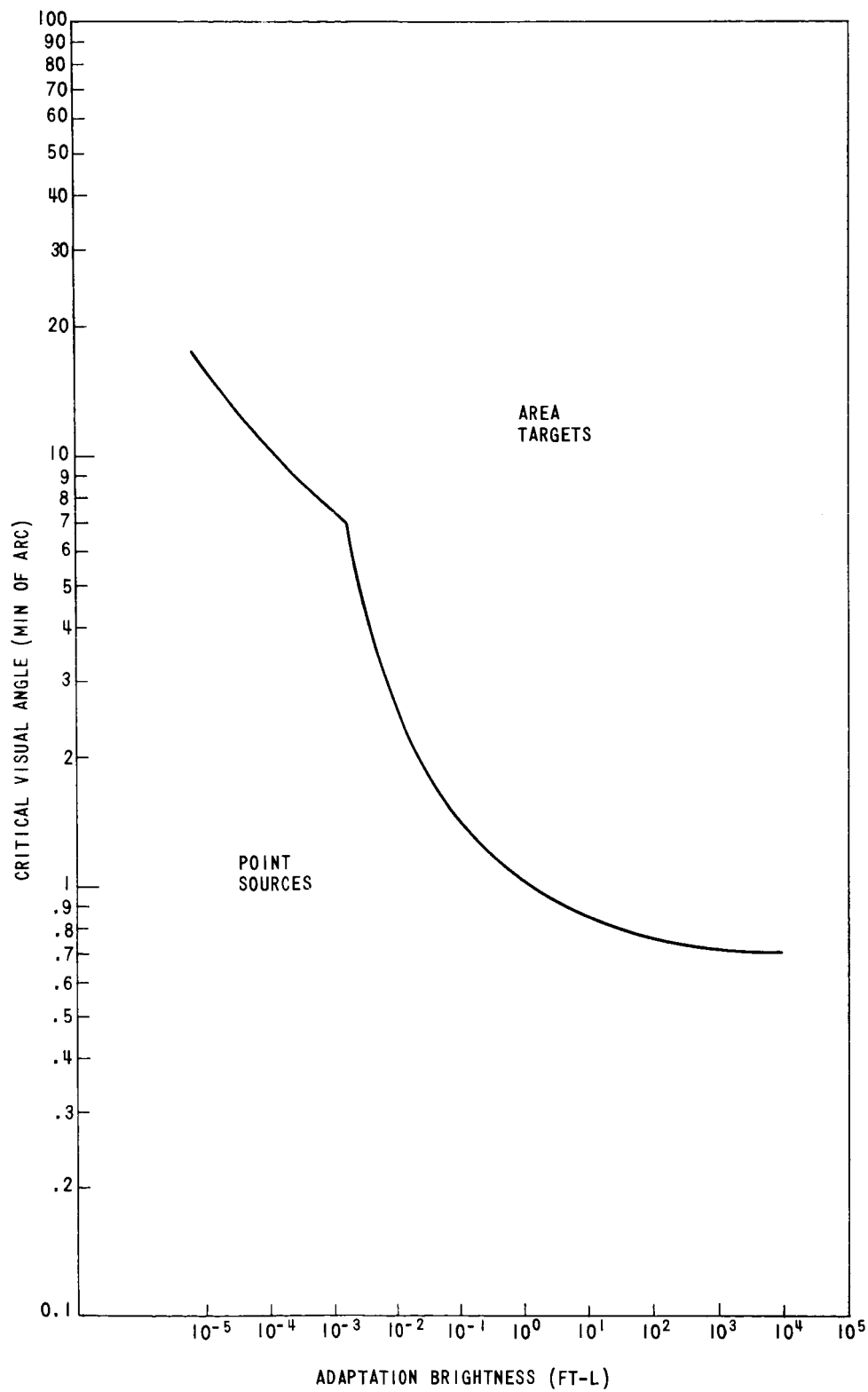WITH SUN ELEVATION ANGLE AT 20° AND 90°

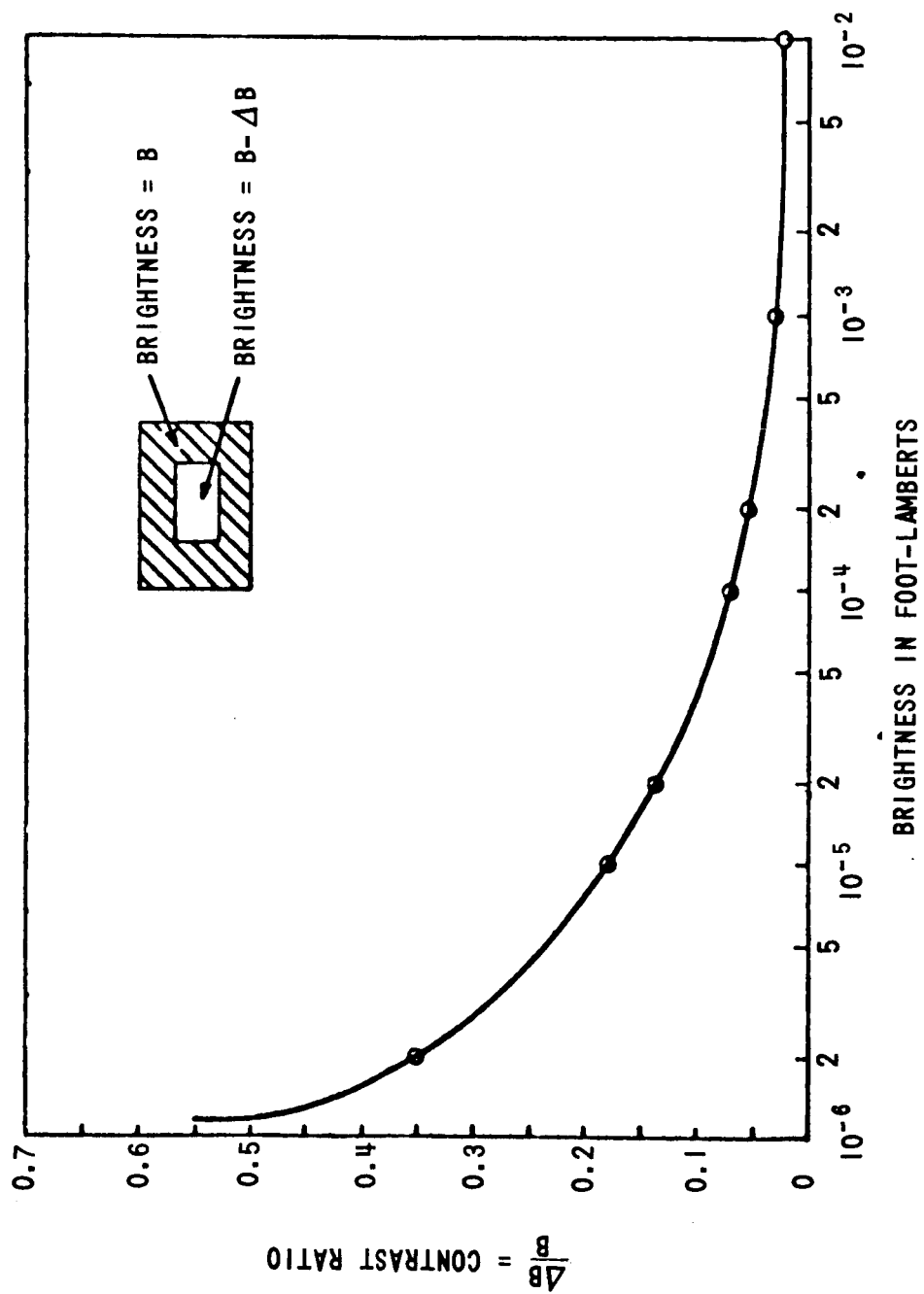FIGURE 9 - CRITICAL VISUAL ANGLE VERSUS ADAPTATION BRIGHTNESS

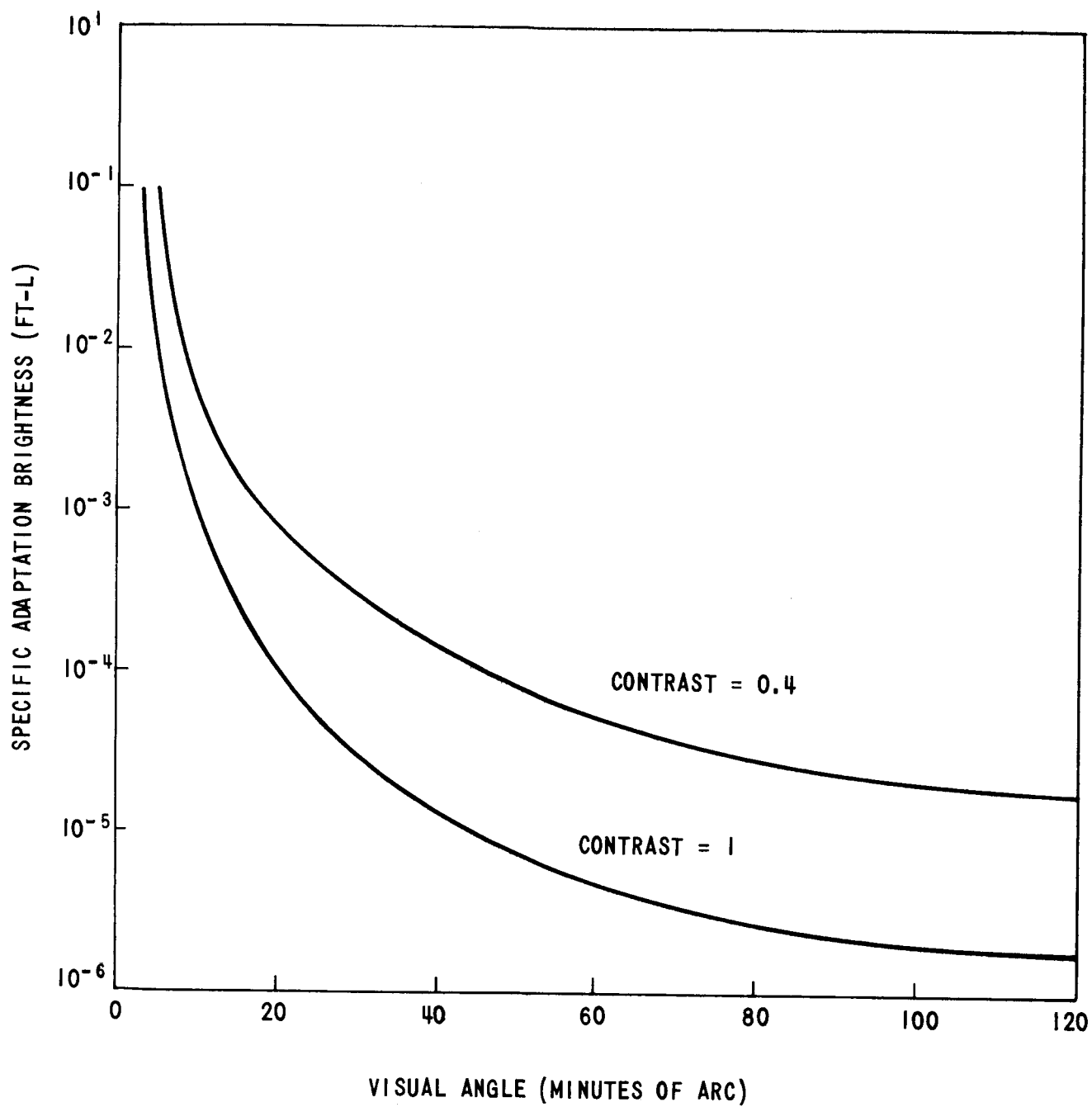FIGURE 10 - PERFORMANCE OF THE HUMAN EYE FOR LARGE AREA PATTERN RECOGNITION WITH VARYING CONTRAST.

FIGURE 11 – SPECIFIC ADAPTATION BRIGHTNESS VERSUS VISUAL ANGLE
DERIVED FROM DATA BY VOS, LAZET AND BOUMAN
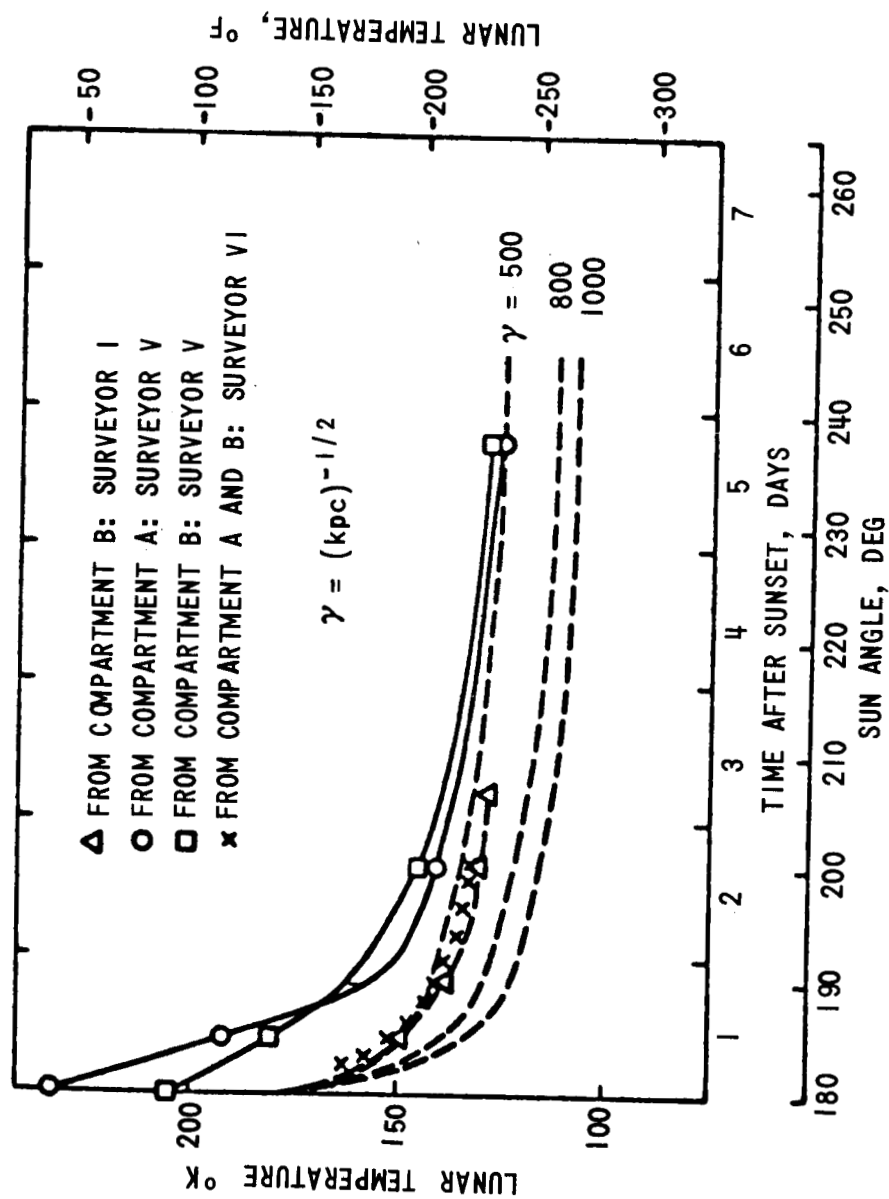(TRESHOLD CONTRAST USED CORRESPONDS TO A PROBABILITY
OF SEEING $P_s < 0.1$)

FIGURE 12 - COMPARISON OF LUNAR SURFACE BRIGHTNESS TEMPERATURES AFTER SUNSET FOR SURVEYORS I, V (ADJUSTED IN TIME FOR SURVEYOR VI), AND VI.
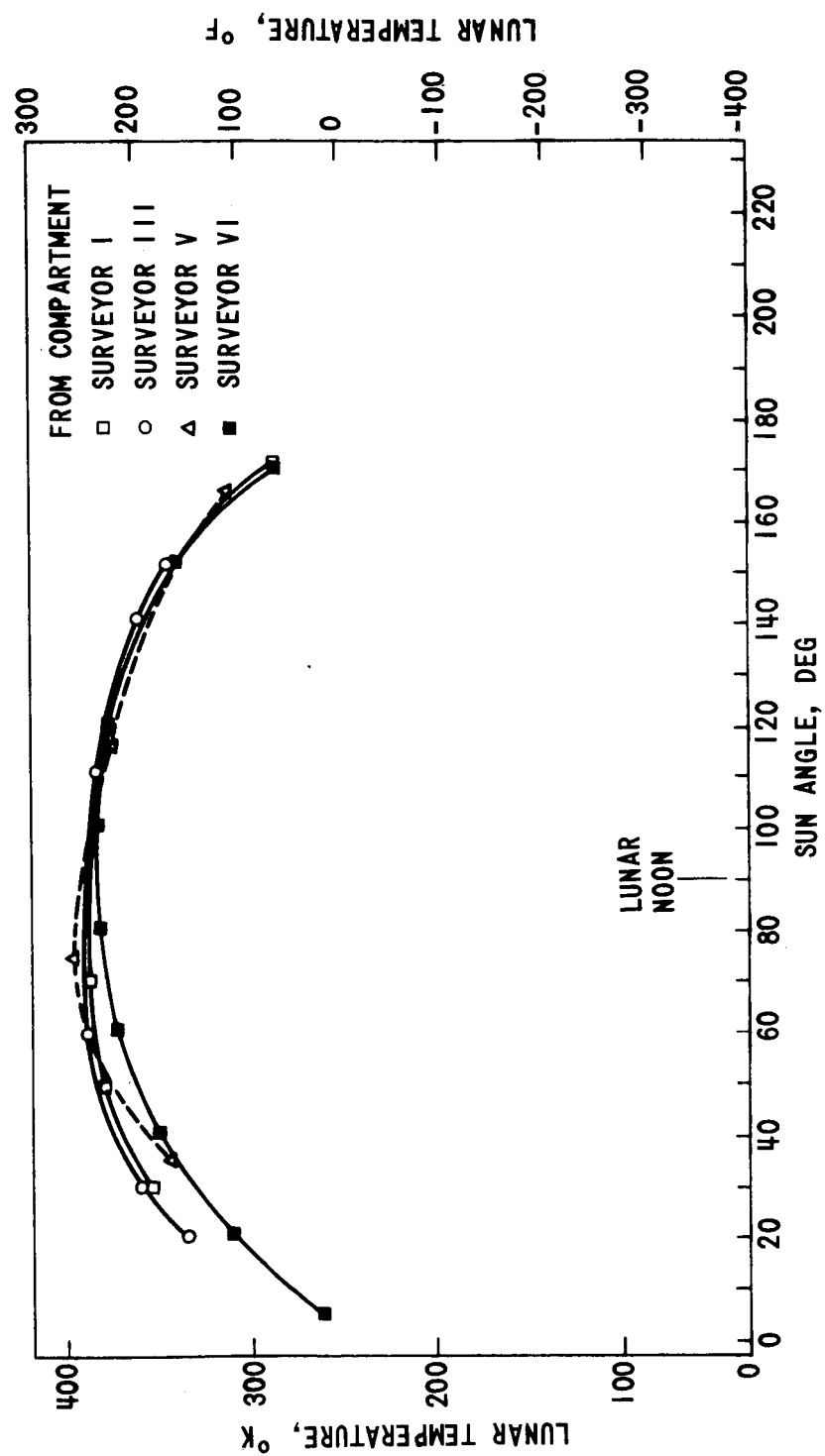
FIGURE 13 — LUNAR SURFACE BRIGHTNESS TEMPERATURE FROM SURVEYOR I, III, V AND VI DATA
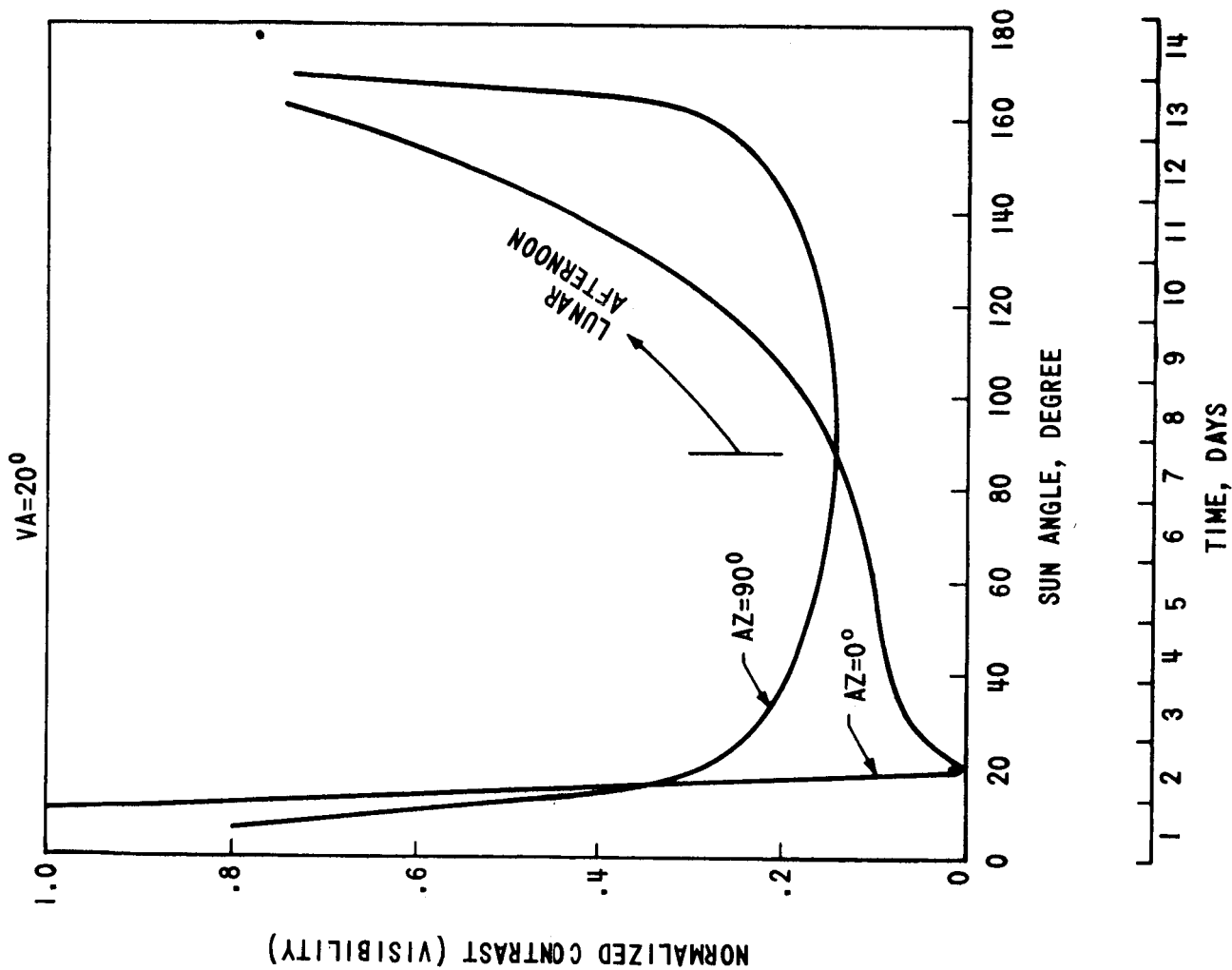
JPL TECHNICAL REPORT 32-1262

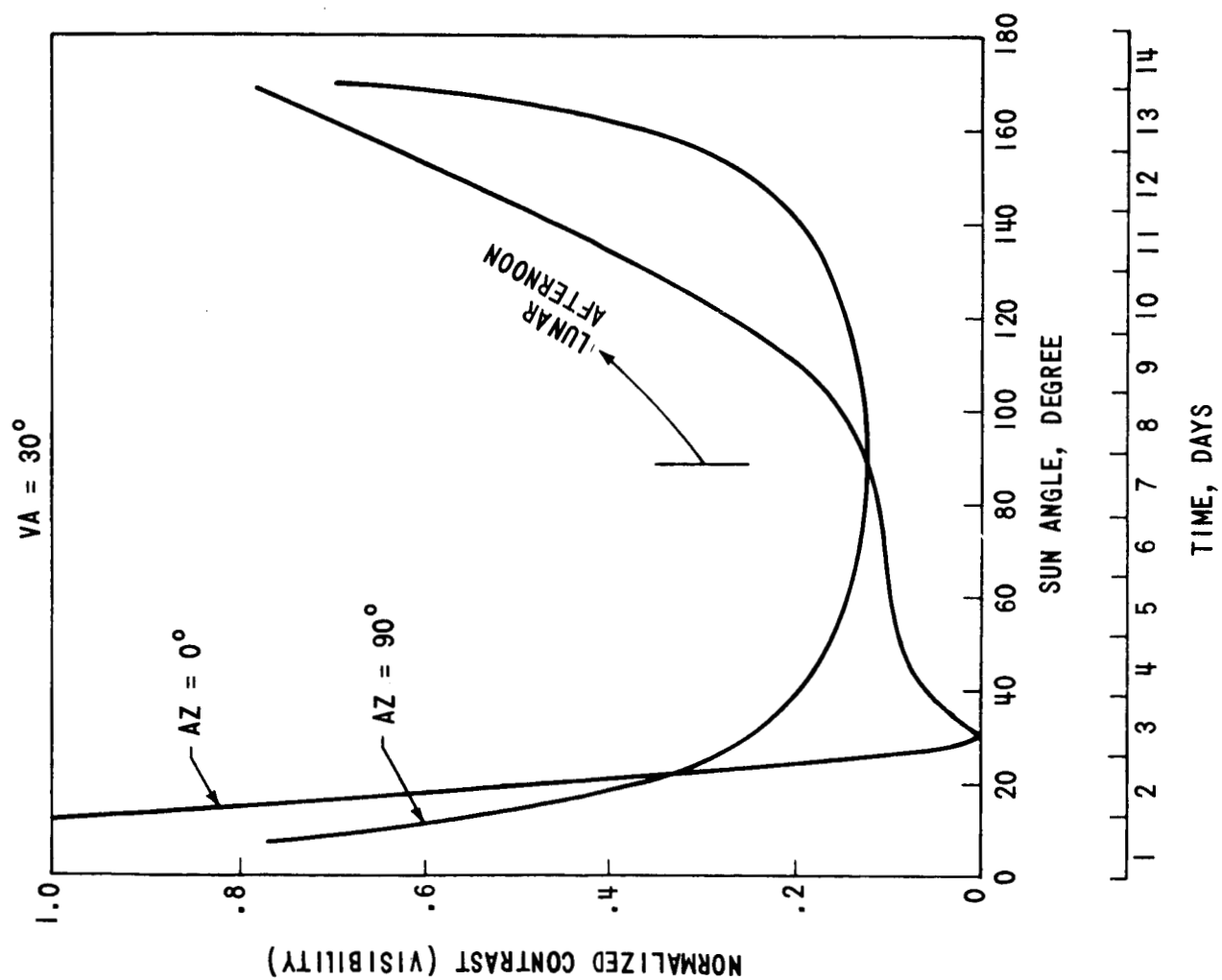FIGURE 14a - THE EFFECT OF SUN ELEVATION ANGLES ON VISIBILITY

FIGURE 14b - THE EFFECT OF SUN ELEVATION ANGLES ON VISIBILITY

APPENDIX

Determination of Mean Contribution of
Earthshine to the Illumination on the Moon

Even though this contribution of earthshine is cyclic during each lunar month, small variations occur from month to month for a given site location. These variations are insignificant for planning purposes. In order to demonstrate the calculation procedure a site location of 40°W longitude and 0° latitude on the particular day of September 13, 1969 at 0^h E.T. (Ephemeris Time) were chosen.

From the 1969 American Ephemeris and Nautical Almanac (A.E.N.A.) page 321

the Earth's selenographic longitude (λ_1) = -4.86°

the Earth's selenographic latitude (ϕ_1) = 1.46°

the Sun's selenographic colongitude (Λ_2) = 288.54°

The Sun's selenographic latitude (ϕ_2) = 0.07° .

From page 63 at 0^h E.T. (GMT) the Moon's horizontal parallax is 56' 14.426".

The phase of the Moon shows that the new Moon occurred on September 12, 1969 and, therefore, the phase angle, θ, will be in the first quadrant. The longitude of the sun is $\lambda_2=\Lambda_2-90°$ or 198.54°. The angular distance between the earth and the sun as seen from the center of the moon can be found from the law of cosines

$$\cos\tau = \sin\phi_1 \sin\phi_2 + \cos\phi_1 \cos\phi_2 \cos(\lambda_2-\lambda_1) \qquad (1)$$

$$\theta = \tau - 180° \qquad (2)$$

The topocentric corrections for 40°W longitude and 0° latitude can be computed from the earth-moon distance and the parallactic shift due to topocentric position. The angular distance of the site location from the earth-moon line centers is

$$\phi_3 = 0° - (\phi_1) = -1.46°$$

$$\lambda_3 = -40° - (\lambda_1) = -35.14°$$

The correction to the center-to-center distance R is

$$\Delta Z = R_m \cos\phi_3 \cos\lambda_3 = 1414 \text{ km}$$

where R_m is the radius of the moon (1730 km). The distances perpendicular to the earth-sun line are given by

$$\Delta X (\text{perpendicular to equator}) = R_m \sin\phi_3 = -44 \text{ km}$$

$$\Delta Y (\text{parallel to equator}) = R_m \cos\phi_3 \sin\lambda_3 = -955 \text{ km}$$

The corrected coordinates for the earth are computed from the parallactic equations

$$R_o' = R_o + Z$$

$$\phi_1' = \phi_1 + \Delta X/R_o'$$

$$\lambda_1' = \lambda_1 + \Delta Y/R_o'$$

where R_o is the distance between centers of Earth and Moon and ϕ and λ are in radians.

The distance R_o is not given directly in the A.E.N.A., but can be calculated from the horizontal parallax of the moon. The equatorial horizontal parallax at distance 60.2665 equatorial radii of the Earth (384,400 km) is 57' 02.70". Thus for this day

$$R_o = 384,400 \frac{\tan 57' \ 02.70''}{\tan 56' \ 14.426''} = 389,900 \text{ km}$$

and

$$R_o' = 389,900 + 1400 = 391,300 \text{ km}$$

$$\phi_1' = .02548 + (-44/389,900) = .02536 = 1.45°$$

$$\lambda_1' = .08482 + (-995/389,900) = -.08737 = -5.01°$$

$$\phi_3' = 0° - (\phi_1') = -1.45°$$

$$\lambda_3' = -40° - (\lambda_1') = -34.99°$$

The value of τ is now computed from equation (1) using (ϕ_3', λ_3') and (ϕ_2, λ_2)

$$\cos\tau = \sin(0.07°)\sin(-1.45°) + \cos(0.07°)\cos(-1.45°)\cos(198.54 + 34.99)$$

$$= -.5942$$

$$\tau = 233° \ 32'$$

and

$$\theta = 233° \ 32' - 180° = 53° \ 32'$$

From Figure 2 the mean contribution of earthshine (the intensity of) to the illumination of the site (40°W, 0°) is 46% of the full-earth value. This is the level of illumination one would get if he positioned a page of a book at right angle to the direction toward the earth. However, the surface brightness of the moon as it appears to a lunar observer will differ depending on the albedo of the surface and on the relative position of the observer's viewing angle, the earthshine elevation angle, and the azimuth angle (angle between the observer viewing line and earthshine source line projected onto the viewing surface).

BELLCOMM, INC.

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         Illumination

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